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Methods of improving the Mississippi River

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METHODS OF IMPROVING THE MISSISSIPPI RIVER

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This is to certify that the thesis of JOHN W. BUZICK entitled "Methods of Improving the Mississippi River", prepared under my direction, is approved by me as meeting this part of the requirements for the degree of Bachelor of Science in Civil Engineering.

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OBJECT OF THESIS.

The object of this thesis is to give a brief description of the methods that have been employed in improving the Mississippi River. The description will include the theory, the construction, and the resulting benefits of such improvements as have been made.

DESCRIPTION OF RIVER.

The Mississippi River, on account of its easy navigation, the many fine rivers that flow into it, and the fruitfullness of the country on each side of it, is the chief of all the rivers in the United States. It rises among a number of small lakes in Minnesota and flows almost due south, emptying into the Gulf of Mexico. The basin of the river consists of nearly all the land in the United States between the Alleghany and the Rocky mountains, which contains approximately one and one quarter million of square acres, or about 41 percent of the entire land area in the United States. The characteristic features of the river are the succession of long, sweeping bends and straight reaches separating them, and the great amount of silt carried by its waters. Some of the largest tributaries are the Missouri, Illinois, Ohio, Arkansas, and Red rivers.

HEADWATERS. The first two hundred (200) miles of the Mississippi river extend from Lake Itasca to Pokegama Falls in Minnesota. The entire drainage area through which the river

passes, is covered with numerous lakes, varying in size from a few square miles up to about 200 square miles. The higher portions of the country are densely wooded, while the lower lands are covered with reeds and rice, large tamarack swamps and bogs. The soil is made up of sand and clay, which makes very stable banks. During the rainy season, this region stores up large quantities of water, and during the dry season, slowly gives it up, thus equalizing the flow of the river to some extent. The river at times is navigable for some distance above Pokegama Falls.

FROM THE FALLS OF POKEGAMA TO THE MISSOURI RIVER. From the falls of Pokegama to the falls of St. Anthony, the river flows between very narrow and stable banks. There are numerous rapids in this section, and in the latter part of it are a large number of small islands. The minimum depth is about 3 feet. Below the falls of St. Anthony, for a distance of 712 miles, to the Missouri River, bank erosion is comparatively slight. The surrounding drainage area is low and contains many swamps and sloughs which, in the upper part of this section, serve as high water channels, but are nearly dry at low water. The bluffs along the river are all of the Silurian formation, and are composed of magnesium limestone, interstratified with softer limestone. The different rates of abrasion of the strata have caused considerable local variation in the appearance of the bluffs, and rock terraces as high as 50 feet have been formed. The flow is interrupted at two different places by rapids, where the bed of the stream is of solid rock. At these places, the navigation has been

improved by constructing canals and locks.

Below the Illinois River to the Missouri River, the banks are alluvial and the river, during high water, overflows the bottom lands to the depth of from six to twelve feet. The channel, however, does not suffer much change, owing to the stable character of its bed. During the times of overflow, large quantities of sand are brought down from the terraces and carried down stream where it is deposited on sand bars, which greatly impede navigation during the following stage of the river.

MISSOURI TO THE OHIO. Between the mouths of the Missouri and Ohio rivers, the bank erosion is more noticeable, due, probably, to the erosive action of the murky waters of the Missouri, and to the softness of the material composing the banks. Hydrologically, the Missouri is the least important of all the tributaries, but in another respect it is the greatest; that is, in the quantity of solid matter which it brings to the Mississippi. Of this, it contributes about two thirds. The extreme variation in height of the river is 36 feet, and the low water slope average is .6 feet per mile. The dry season commences in September and continues through the winter months. In this section, sand bars are numerous and their location is constantly shifting. The banks below the Ohio are subject to rapid change, being torn down at one place by the erosive action of the water, and built up at another by the dropping of sediment, due to the diminished velocity of the current. The change is so rapid that boats pass down the river, where, but a few hours before, the plow

had been at work. Such rapid changes prohibit the location of permanent works near the river.

During high water, sand waves, which lie dormant during the ordinary stages of the river, are started down stream, and new sand bars formed. During the falling stages of the river, the water becomes more charged with sediment, and whenever the velocity of the current is reduced, silt is deposited. In a short time the water becomes comparatively shallow over the sand bars and silt deposits until channels are cut through them by the concentration of the current.

Low water conditions between the Ohio River and the Red River last about a month, the low water slope averaging about 0.35 feet per mile. The greater part of this section has water deep enough at all times for the demands of navigation. South of the Red River, the outlet is narrow and deep. The banks are fairly stable and sand bars, as obstructions to navigation, are almost unknown. There is very little need of improvement as far as navigation is concerned. The maximum oscillation is about 50 feet, tapering to zero at the Gulf. At New Orleans, the depth is 150 feet, but this gradually decreases to 35 feet at the Head of the Passes.

THE PASSES. On account of the diminished velocity of the water, caused by the entrance of the river into the Gulf, a large amount of the material carried by the water in suspension, is deposited, and this tends to choke the mouth of the river. The bars thus formed increase to such dimensions that the only way for the water to reach the sea is to force a

channel through them. The three channels thus formed are called Pass al'Outre, South Pass and Southwest Pass. At the two points of land where the three passes separate, the river is 11,000 feet wide. At the upper end of the passes, the deepest part of the river bed is 90 feet below the surface of the ground, and at a point about a mile below the head of the passes, at Cubit's Gap, the depth is only 60 feet. Each pass is comparatively wide and shallow at the upper end and gradually becomes narrower and deeper in the middle. At the mouth, they widen again, and when land's end is reached, all trace of distinct banks are lost and bars spring up having a depth on the crest from 7 to 13 feet for a width of about 2 miles. The advance of these bars into the Gulf is at the rate of about 78 feet per year.

The South Pass, in 1894, was about 11 miles long and 750 feet wide. The velocity was 3.1 feet per second, and the total discharge about 55,200 cu. feet per second, or 7 percent of the total of the river. The maximum depth in the last fifty years ranged from 53 to 60 feet, and the minimum has been as low as 7 feet.

Pass al'Outre has a length of about fifteen miles and a depth of about 30 feet. This pass discharges about 50 percent of the water of the Mississippi a velocity of from 3.9 to 4.2 feet per second. In 1875, the bar became badly filled with mud lumps which greatly hindered navigation. The lumps rise as high as 10 feet and 15 feet above water and vary in size from a few square feet to an area of 30 acres. The material composing them is a sticky clay, and they are

supposed to be formed by the pressure of the advancing bar.

The banks of the passes are so low that at high tide and high water combined, the water overflows them for nearly their whole length. The banks are also very weak, and some notable crevasses have been formed in them; one called Cubit's Gap, which has been briefly described, and one called The Jump, being the most important. A great deal of the extreme high water passes through the Atclafalaya River, some through breaks in levees, and some through The Jump, Cubit's Gap, and the minor outlets. About 77 percent of the water passing New Orleans reaches the Head of the Passes.

IMPROVEMENTS.

OBJECT OF IMPROVEMENT. The object of the improvement is, first: to protect the bottom lands from overflow, and second: to facilitate navigation. Up to about 1878, the people were more interested in protecting the bottom lands from overflow than they were in improving commerce. The cost of all improvements was paid by the states, municipalities, and individuals. The traffic soon began to increase to such an extent that nore extended improvements were necessary in order to make a way for shipping the increasing produce. The Government then became interested and took up the work, placing it in the hands of United States Army Engineers. A few years later, a commission was appointed to further carry on the work. Since that time, large sums of money have been been spent by the Government and the states toward improvements.

METHODS OF IMPROVEMENTS. The following methods have been used in improving the water-way.

1. Levees. 2. Dredging. 3. Revetment. 4. Contraction works. 5. Jetties. 6. Reservoirs. 7. Canals and Locks.

LEVEES. The subject of the levee will be taken up first, since this mode of improvement has, of those tried on the Mississippi River, been the most extensively used. The conformation of the flood plains of this river is such that it is rendered very favorable to protection by levees. The hills which border it are spaced in such a manner that the bottom land is divided into coves or basins which are usually separated at either end from the adjoining basins by ridges which are above overflow and which, therefore, afford points of support for independent levee systems. The objects of the levee are not only to prevent the destruction of life and property by flood, but to maintain a navigable channel during low water.

The first levee constructed along the Mississippi River was at New Orleans, in 1817. It was 18 feet wide and about one mile long. It extended along one of the streets of the city, and was used as a roadway. As the country began to develope, the levees were gradually extended, but were of a very inferior type, being only about 4 feet high. In 1850, the Government, to provide a fund for the construction of levees, gave to the states all the unsold swamp and overflow lands within their border. This greatly stimulated interest in the building of the levees for a few years, but during the Civil War work on them had to be stopped. Shortly after the war, the work was again taken up with renewed energy. The work was not done, however, in concert, and during the flood of 1874, many of the

levees were washed out. They were again built up and again destroyed by the flood of 1882.

In June, 1879, Congress created a body known as the Mississipi River Commission. This consisted of 7 men whose purpose was to determine and permanently deepen the channel of the river, to protect its banks, to improve navigation, promote and facilitate commerce, and to prevent destruction by floods. The portion of the river between Cairo and the Head of the Passes was the part most needing repairs. None of the funds appropiated by the Government were to be used for repairing or building levees for the purpose of protecting the lands from overflow, although such levees might be constructed, if necessary to deepen the channel and improve navigation. In 1880, the river was first subjected to continous observations, and in 1882, the first appropiation was made for levees by the commission. By the act of Sept. 19, 1890, the general repair and construction of levees was first authorized without qualifying restrictions, and since then, this work has formed one of the most important items in the operations of the commission. Up to February, 1904, $17,500,000 had been spent by the Government, and $40,000,000 by the municipalities. By the acts of 1904 and 1905, $2,000,000 were appropiated annually for river improvement, one half of which was to be spent for levees. At present there are more than 1,500 miles of levees or more than 72 percent of the number of miles needed for a perfect system. The present levees are from 2 to 4 feet above the gauge readings of the highest floods, and as the system approaches completion, it is being made stronger and safer.

Much adverse criticism has been given the Commission on account of the building of levees to facilitate commerce. It is claimed by the Commission that the levees operate to prevent the formation of the sand bars ~~formed~~ during high water, while McMath believes the contrary to be true. The following objections have been made to levees:

1. They break too easily and too often. 2. They raise flood heights. 3. The cost is excessive. 4. They cause the river bed to rise because they do not permit the escape of water over the bank during floods.

The following are the resolutions passed by the Interstate Mississippi River Improvement and Levee Association on October 27th, 1903.

"1. After years of actual observation and experience, and supported by the opinions of engineers, whether from the engineering corps of the Army, or from civil life, we desire to affirm that we have the most absolute confidence in the effiency of the levee system, when built according to correct standards, to protect the Mississippi River from overflow.

"2. There was no warrant for the assertion that the effect of levee construction has been or will be to raise the bed of the stream, but, on the contrary, it is our definite conviction that the effect will be to cause a general and considerable lowering of the bed.

3. The Association is opposed to the scheme of reducing flood heights of the lower river by the construction of reservoirs and so-called outlets."

These conclusions have been based upon the work of the Mississippi River Commission. An elaborate and careful investigation was made by the Commission which disapproves the notion that the immediate effect of levee construction is to cause the river to rise. A comparison of surveys made in 1881, 1882, 1883, 1894 and 1895 and 1896, shows a general tendency to the establishment of a more uniform channel in the depth and width, and the lowering of the crests of the low water and high water bars. The reservoir system has been claimed by the Commission to be impossible on account of cost, and the outlets to be impracticable and harmful.

The effect of a complete levee system is shown by the following:

Year.	No. of Crevasses.	Flood swept away. Miles of levee.
1882,	282	54.4
1897,	38	8.7
1903,	7	2.5

The levees are plain, earth embankments, without puddle walls or foundations of any kind. The choice of materials used in their construction is very limited. The different kinds of earth to be found are sand, clay, and loam. None of these materials are found pure, but these three are intermixed to a certain extent, the clay being the best for levee construction. If the sand is used alone, it will not compact, and is easily washed away. The loam is made up of such fine particles that it will not hold together well when it becomes subject to the erosion of the waves. The clay forms a very

suitable levee, but this cannot be found except in few localities. In the main, however, the kind of material used is limited to the distance to be hauled .

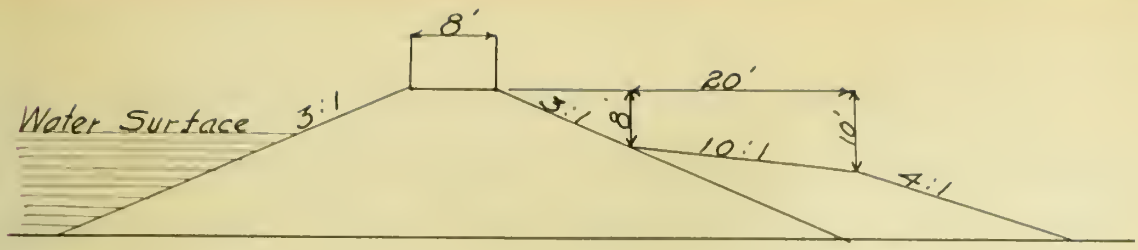
In building a levee, the first thing to do is to clear the ground thoroughly of all trees and vegetable or other extraneous matter. Stumps are either grubbed out or blown out by the roots, Judson powder being used for the latter purpose. The ground is next thoroughly cleared of all leaves and trash and well broken with a plow so as to form a good bond with the new earth. The work is built from the beginning out to the slope stakes, to avoid the necessity of dressing it afterward with a light coating of earth, which is apt to slip or wash off with the first heavy rain.

There are two natural conditions existing along the lower Mississippi, which greatly adds to the practicability and effiency of the levee system.

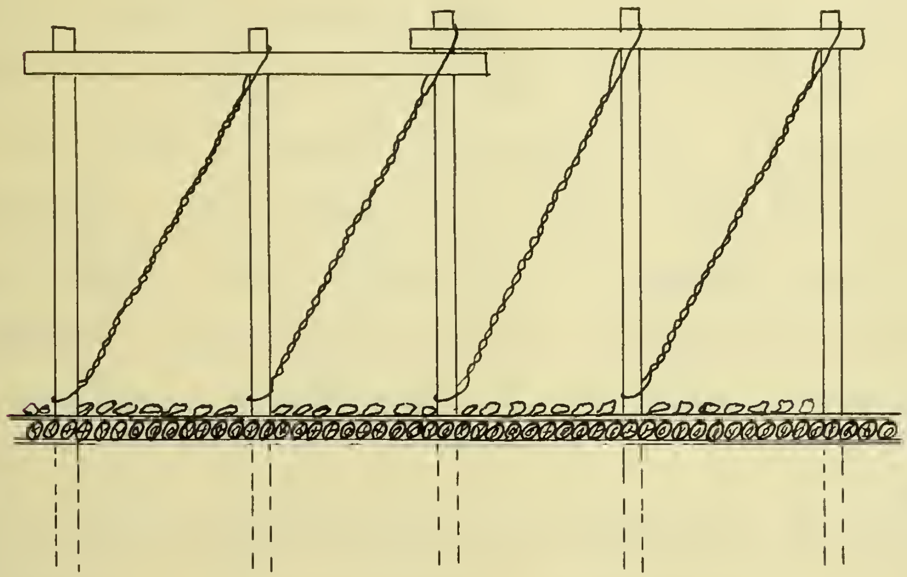
1. Bermuda grass, which forms a dense sod and resists the wash of the waves can be grown on the levees and thus form a good protection against erosion.

2. The high charge of sediment carried by the water during times of flood helps fill up the voids in the soil composing the levee by being deposited as the water seeps into the embankment.

The usual dimensions adopted are a crown of 8 to 10 feet, and slopes of 3 to 1. In the case of sand or loam, these dimensions are usually increased. The Lake Bolivar levee in Mississippi has a crown of 15 feet and slopes of 5 to 1. This levee is 25 feet high and composed of nearly pure, white



Standard Levee Section.



Five Pile Dike.

sand. Very frequently, to increase the strength of high levees, a banquette or "bench", as shown in the accompanying figure, is used. In the lower Yazoo district a crown of 20 feet and a slope 5 to 1 are used. Banquettes are also used when the foundation is extremely unstable. When such is the case, the pressure of the water tends to "blow up" the ground on the land side and thus cause a caving in of the levee. 5 breaks that occurred in the lower Yazoo district in 1890, are all supposed to have proceeded from this cause.

In the district between Cairo and Vicksburg, the standard dimensions are, crown, 8 to 10 feet, river and back slopes 3 to 1 for clay. If sand or loam are used, all dimensions are increased. All levees over 11 feet in height have a banquette added. This construction is made as shown in the following diagram. The height is usually 3 or 4 feet above the highest known flood, some of them having a height of 40 feet.

In the lower district south of Vicksburg, the dimensions of the standard sections adopted vary with the height, and are intended to conform more nearly to perfect sections. The crown is made 8 feet in all cases, but the slopes on both sides vary with the height of the levee. For levees 10 feet high, the river slope is 3 to 1 and the land slope 2-1/2 to 1. For heights of 10 to 15 feet, the river slope is 3 to 1, and the land slope, to within 5 feet of the crown, is 4 to 1: from thence to the crown, it is 2-1/2 to 1. For heights of 15 to 20 feet, the crown and river slope is the same as above. The first eight feet of the land slope is 6 to 1, the next

six feet is 4 to 1, and thence to the crown 2-1/2 to 1. The berm of the water is usually 30 feet. The levees are in almost every case constructed in two foot layers by means of scrapers and sodded at two foot intervals with Bermuda grass. .

The levees so far constructed have proven by far to be the most successful improvement yet tried on the Mississippi River.

DREDGING. On account of the large number of sand bars that are formed annually in the Mississippi it was deemed advisable to either improve the river in such a manner as to prevent their formation, or to devise means of cutting them out. Small dredges have been used with varying success in the passes at the outlet of the river since about 1837. In 1857 and 1858, the Southwest Pass was deepened by stirring and harrowing, but resultsobtained were not satisfactory. About two years later, a stirring and scraping device in the form of a dredge was built by the United States and tried on the Passes. This form of dredging was kept up in the Passes until the completion of the Jetties in 1878.

About 1890, the demands for an open channel became so great that it was decided to try to remove the sand by dredging. In 1893, a dredge was ordered to be built as a sort of experiment. It was of a hydraulic type, equipped with two different pumps, a Reynolds screw, and an Edwards centrifugal pump. After a few days test of the two pumps, it was found that the Edwards centrifugalpump gave the best results. The amount excavated per second was from 37 to 45 cubic feet, of which from 2.5 to 4 cubic feet was sand.

The greatest disadvantage of the dredge, was that it was not self propelling, but had to be moved up stream by means of cables wound around the drums of the hoisting engines, the other end of the cable being attached to steel pipes about 600 feet distant. The waste pipes through which the excavated material was carried away were not long enougn at first, and part of the material was washed back into the cut by the strong current.

The results obtained by dredging, notwithstanding a great many defects, were even more satisfactory than had been anticipated, and in 1895, the Mississippi River Commission passed resolutions, authorizing the construction of another dredge similar to the one already built. Circulars were sent to all the leading dredge builders in the United States, stating the purpose for which the dredge was to be made, and, as nearly as possible, all the conditions under which it was to work. Many good designs were offered, and one was chosen which would have a capacity of 1600 cubic yards per hour. The contract price was $172,775. The dredge was delivered in 1896, and in the ten short tests made with it, the average discharge was 4920 cubic yards per hour. It proved, however, to be too large to be used to advantage on shallow bars, the draught being 6-1/2 feet. The following year, four more dredges were contracted for, two to have a capacity of 800 cubic yards per hour, and two to have a capacity of 1000 cubic yards per hour, each. Thetotal cost was $418,470 for the four dredges.

In 1904, there were ten dredges under the charge of the Mississippi River Commission. They are all of the same

general design as the first, except that they are equipped with propellers, and that the discharge pipe is carried entirely above the water, on pontoons.

The greatest objection to this form of improving the river for commercial purposes is, that the channels made by dredging, are of short duration, the effects lasting but one season. With the dredges now at hand, a channel 250 feet wide and 9 feet deep can be maintained without much difficulty, so it seems as though the advantage of this system outweighs the disadvantages. Whether a channel 30 feet deep could be maintained or not is a very doubtful question, but if it could, this method of improving navigation would probably be the best yet tried.

JETTIES.

There has been no improvement on the Mississippi that has caused so much discussion, as that of the Jetties, at the mouth of the river. The people realized that without a good outlet, there was no use of trying to improve the rest of the river. In 1852, a board of Army officers were instructed by the War Department to report on plans of improving the Passes. The board recommended, together with three other methods, that parallel Jetties should be constructed, five miles in length, at the mouth of the Southwest Pass, to be extended into the Gulf annually, as experience should show to be necessary.Large sums of money were spent on other forms of improvement, but the last recommended was not tried.

In 1874, another board of United States officers was

ordered to report on the feasibility of improving one of the natural outlets. They objected to the Jetty system for the following reasons. 1. That the Jetties would be undermined at the sea ends. 2. That the foundation on which they would rest was unstable, and 3. That there would be a greatly accelerated advance of the bar after the jetties were constructed. General J. G. Bernard, dissented from the report of the majority, and a heated controversy arose.

In February of the same year, Captain Eads made a formal proposition to the Government to open the mouth of the river and maintain a deep channel between the Southwest Pass and the Gulf, for $10,000,000, on the principle that if he did not succeed, he was not to be paid. The Arny Engineers, and most of the people in New Orleans and St. Louis objected to his plans, and the subject was discussed all over the United States. The Government sent a board of three military and three civil engineers to Europe to study jetties. The board reported favorably on the jetty plan, and Eads made an offer to make a thirty foot channel at Southwest Pass, and maintain it for twenty years for $11,000,000, $5,250,000 to be paid him on the completion of the work, and $250,000 to be paid annually, if the work proved satisfactory. The House passed the bill for the Southwest Pass, but through the influence of Mr. Eads enemies, the Senate amended the bill to apply to the South Pass on the grounds that it was the route suggested by the Army Engineers and the board. Mr. Ead's objections to the South Pass were: 1.That an extensive shoal existed at the head of that pass, which it would be difficult to remove,

and that the channel obtained through it would be difficult of navigation, and 2. That the channel through the pass was too small for easy navigation, and inadequate to the growing wants of commerce. Although Mr. Ead's bid was made on the Southwest Pass, he changed it to the South Pass, when the bill was passed authorizing the work on March 3, 1875. The specifications called for a channel 30 feet deep and 350 wide to be built and maintained for 20 years, at a cost of $5,250,000 when the work was completed, and $100,000 annually for 20 years. In 1879, the bill was amended, reducing the dimensions of the channel, so as to read 26 feet in depth and not less than 200 feet wide at the bottom, and 30 feet deep without regard to width.

CONSTRUCTION.

After a careful study of the chart made by the U. S. Coast Survey, Mr. Eads laid out the lines of the jetties. The following considerations determined their location: 1. To place them at such a distance apart as would make them secure against any subsidence of the ground on which they were to rest, that might be induced by the excavation of a deep channel near them. 2. To direct the discharge into the littoral current, and not against it. 3. To inclose the natural channel within the jetties, and thus leave the shoalest water on each side of it, in which to construct the jetties, and thus lessen their cost.

In following this plan of action, the first lines of jetties were constructed parallel at a distance of about 1000 feet apart. The East jetty was built of willow mattresses

and stone, and was about 2 miles in length. The West jetty was of the same construction, but was only a little more than one and one quarter miles in length, not including the Kipp dam, which is about 550 feet in length, and connects it with the west shore. This dam was the first finished.

The depth of the water increased gradually from the shore line to eighteen feet at the West jetty. A row of piles eighteen feet apart was driven and a whaling-stake of 6 x 12" timber was bolted to them. Foundation mattresses, sixty feet wide and two feet thick were sunk above them. On the first course, wooden aprons, sixty feet in length, were placed in a vertical position, rising two feet above the datum plane. These aprons were sections of wooden dams constructed and sunk, as follows: The ways on which they were constructed, were built like mattresss ways, but of lighter material, the timber being 4" x 4" scantling, placed five feet apart, and extending back from the river about 25 feet. Two battens were at first laid down on the ways at right angles to them, the distance between these battens corresponding to the width of the apron. Three inch plank, laid close together, were then spiked across these battens, the tops being even and the lower ends, uneven, to conform to the irregular slope of the mattresses on which they were to rest. Two battens were then spiked to the upper surface of the planks, immediately over and lengthwise with those placed underneath. The apron was then launched from the ways by the tug, and towed to its place along the dam. The pile driver then raised it into a vertical postion, the force of the current pressing it closely against the guide

piling. It was then forced down to the mattresses by means of levers and the pile driver hammers. Piles were next driven on the up stream side of the apron and bolted to the guide piles, thus pinning the apron to its place. A timber was then bolted across, above the apron, to prevent its rising at flood tide by its bouyancy, or by the lifting power of the waves. A second course of mattresses, thirty-two feet wide and two feet thick was next laid horizontally on the up stream side of the aprons and against them. The aprons along the whole length of the dam were put in place in one day.

Along the East and West jetties, mattresses were laid along the apron work on the sea side of the guide piles. The foundation mattresses were 35 to 50 feet wide and 75 feet to 100 feet long. Later on, both jetties were surrounded by a course of concrete blocks, built in place for a quarter part of their length, the heaviest blocks near the seaward end and weighing 260 tons. To prevent the action of the waves, spur cribs were built and placed 100 feet apart on both sides of jetties, where they were exposed to waves. The cribs were built of Palmetto wood. The sides of both jetties were completely surrounded by cribs and capped with heavy rubble stone and a concrete parapit. After one year's work had been done, it was found that the scour in certain localities was not proceeding as rapidly as desired, and it was decided to contract the channel between the piers of the cribs by wing walls. These were made of vertical mattresses, resting against a row of piles, joined by a walling piece. A short time afterward, these dams were raised to the surface of the

water by mattresses laid horizontal.

In 1882, inner jetties were constructed inside of the first lines and 800 feet apart, for the purpose of contracting the channel and preventing the river water from escaping. Spur dikes were built soon after, to still further narrow the channel, until now, it is only 600 feet wide. This final arrangement was necessary in order to secure the required velocity to produce the necessary scour. These Jetties were composed of two parallel rows of piles driven 6 feet apart, and the intervening space filled with willows, weighed down by stone. There is some leakage through them, but not enough to interfere with the purpose for which they were built.

In 1889, a concrete wall was constructed on the inner side of the old wall, which used the old mattresses as a foundation. This wall was covered with stone for a depth of 2 feet. The foundation was thus brought up to a level with the average flood tide and on it was constructed a concrete parapet with a top width of 3 to 4 feet. The river side is vertical, and the slope of the seaward side one to one. The height averages about 3 feet. This new construction has not, as yet, been damaged by storms.On account of the small volume of water in the South Pass, dikes were constructed at the head of the Pass and a mattress was built across both the Southwest Pass and Pass à l'Outre for the purpose of diverting the water into the South Pass.

Since 1895, the Government has kept open, a thirty foot channel at their own expense by means of dredges. The vessels,

however, increased to such a size during the 25 years following the opening of the passes that the ones of the greatest carrying capacity and the lowest freight rates were shut out of the river by lack of water over the bars. A great many delegations appeared before the House Committee of Rivers and Harbors, appealing for a new and deeper channel through the Southwest Pass, and on June 19, 1902, Congress authorized the improvement.

The new jetties in the Southwest Pass are a great deal larger than the ones in the South Pass, but were constructed on the same general principles. They consist of two parallel walls, about a half mile apart, and four miles long. The general construction is also the same as that of the South Jetties. Tiers of willow mats were built up and held in place by means of rock ballast, and frames of wood. Between the wooden frames of yellow pine, willows were laid, and on top of this, a concrete capping is placed. The general dimensions of the capping are: bottom width, 12 feet: top width, 8-1/2 feet, and thickness 4-1/2 feet. The foundation mattresses are from three to four times the width of those in the old Jetties, or about 150 feet. This increased width is for the purpose of preventing scouring. They are built about 200 feet long and from two to five tiers deep, depending on the depth of the water. In a few more years, the bottom tiers will sink into the mud, and the whole structure, on account of the great weight of the ballast, will become as strong as the natural banks of the river.

The work on these jetties was completed in 1908, and have proven a success. The minimum depth of water is 35 feet, and the width 1000 feet.

Of all the work done on the Mississippi River for the improvement of commerce, none has proven as successful as that done by means of jetties. It is true that there were a few cases of the jetty banks breaking, but no serious defects have occurred.

CONTRACTION WORKS.

The contraction works were begun about 1880, and were kept up until 1890. The first works were begun at Plum Point Reach, Tennessee, and at Lake Providence Reach, Mississippi The excessive width of the river and the action of the sand

bars at these two places, made it very hard to maintain a channel there. It was thought that a system of parallel dykes, limiting the width of the main channel of the river to about 3,000 feet would produce a current sufficient to scour out the bars then existing, and to maintain a permanent channel 10 feet deep. The dikes were to be built principally of brush, anchored firmly in place by piles, and compressed enough to impede the flow of the water when it passed through them, thus diminishing its velocity and causing it to deposit the sediment carried in suspension just outside of the dike, and in this manner, a new shore line would eventually be built up. Trainning walls, parallel to the course of the river, were to be used in conjunction with the dikes to prevent the formation of eddies.

Longitudinal dikes were first constructed for the purpose of confining the width of the river to the desired size, and then cross dikes on lines perpendicular to the direction of the current were built to retard the velocity between the longitudinal dikes and the shore. The dikes consisted of two rows of piles driven through mattresses placed at the bottom to prevent scour. The piles were spaced from 10 to 12 feet apart, with the piles in each row 8 feet apart, center to center, and corresponding ones in the two rows placed directly opposite each other. The depth driven was from 15 to 20 feet, and the height was limited to 15 feet. They were held rigidly together by means of wooden cross braces and diagonal wires. The mattresses at the bottom were made of brush mats, and were 30 feet wide, and extended from 10 to 15

feet on each side of the piles. The mats were firmly bound together by twine or wire, and then loaded with stone and made to slide down the piles to the bottom.

On the cross dikes, screens with about 75 percent of openings were suspended. These screens were sunk in 100 foot sections, and were from 6 to 8 feet wider than was needed, in order to reach the bottom of the river. They were built of poles and brush, the brush being placed horizontally. At the top of the screen, a double stringer of poles were bolted and wired to the piling. The longitudinal dikes were built without screens and had, instead, a foot mat ranging from 50 to 100 feet out from the bottom of the piling to prevent scouring out by the deflection of the current. All dikes built after 1884, contained from three to five rows of piling, and the curtain or inclined matts that were first used on cross dikes were replaced by wattling which was found to be more efficient and cheaper. The wattling was made by fastening poles of 3 to 6 inches in diameter, horizontally to the piles.In the three row dikes, the wattling was placed on the middle row, and in the five row ones, on the second and fourth dikes.

The total cost of the entire works at Providence Reach was $3,000,000. This whole amount proved to be wasted. In 1886, the Commission, by an act of Congress, was restricted from using any part of their appropiations for the purpose of building revetments, and the extensive revetment work thus being carried on at Louisana Bend had to be stopped. The banks at this bend were so unstable that, by 1888, when the Commission were again empowered to use appropiations for

revetment work, they were so changed that the dikes that had been built in the river were left on dry land, and thus, the whole work proved to be a loss.

The work done at Plum Point proved to be more successful and showed conclusively that the theory of contraction dikes was sound. It was also proved that, although the dikes were successful in their purpose, they were too expensive to be used. It is now considered that the work of bank protection should precede the permeable dikes and other structures of that class, and that the latter may be regarded as supplementary in function, and as necessary only in the minority of cases. By means of bank revetment, the engineers are able to hold the Mississippi rigidly in its channel, for the current is thus prevented from eroding the banks, which is the first step in shifting. By holding the current in a fixed channel, the same revetment, aided by dikes from opposite shores, makes the river scour the channel deep and clear in its fixed positions. The Commission has spent about $11,000,000 on revetment and contraction works, or about one quarter of the total amount spent on improvements by this Commission.

BANK REVETMENT.

The purpose of the bank revetment is to prevent a change in the position and in the flow of the river. This is brought about by protecting the banks from caving, which, in turn, reduces the load of sediment that is constantly forming bars below. By protecting the banks a normal width and depth is maintained in the bends, and valuable property is protected against the danger of being destroyed by the constant action of the currents. There are two classes of caving; that caused by abrasion, and that caused by the combined action of seepage water and the undermining of the foot of the slope by the current, termed sloughing.

Although brush and stone revetments had been used for the protection of river banks in Asia and Europe for many years, they fell far short in magnitude when compared to the ones placed along the Mississippi. Some of the latter had an area of from seven to eight acres and had to be sunk to a depth of 80 to 100 feet in a current ranging from 5 to 8 feet per second.

The early revetment work was purely for the protection of property in harbors, and not for the improvement of navigation. Before 1879, the work consisted of piles, dykes and training walls, and were made, more to control and rectify the channels, or to close the chutes. The work now consists principally in removing snags, stumps and brush, and the placing of sheathing for the bank, made of willows or plank, called mattresses. This work is divided into two general

classes, the continous revetment, and the submerged spurs. The mattresses are usually composed of a network of willows formed into a mat, and are placed on that portion of the slopeextending from deep water to a few feet above the water level, and are weighted down with stone to hold it in position.

CONTINOUS REVETMENT. The first continous revetment work was begun in 1879, but was of a very small scale. It was only a protection for the bank under low water, it being assumed that the bank would take care of itself under other circumstances. About one year later, it was noticed that the upper banks also needed protection and they were then graded to a slope of about 45 degrees and covered with mattresses 8' thick. The first mattresses were built of fish pole cane, sewed together by weaving double wires and yarn under and over them. They were about 2" thick, 25 feet long and 24 feet wide, and were fastened by large iron rings to piles driven in pairs about 6 feet apart. They were made in the form of sections 200 feet by 24 feet, and sunk with iron weights. These were of little value.

A new form of mattress was tried in 1882, but it was not as successful as the first ones- They were built very loose, and the water washing through the openings soon undermined them. The mattresses were built of grillage and brush, bound by poles and brush, covered with rock, and connected at the water line to subaqueous work. As this form of construction did not prove satisfactory, stronger and more pliable structure was tried, which was called the facine mattress. The first

one was constructed in 1892. This proved so much superior to the other forms tried that it was adopted as a standard.

CONSTRUCTION OF THE FACINE MATTRESS. Before the revetment is laid, the banks are cleaned of timber and debris for a width on the river side equal to about three times the height. Pile abutments are built at the ends, and a number of barges moored to them. In this construction, a large number of barges are required. They are firmly tied together at the ends and swung out into the stream just opposite the site the mattresses are to occupy. These are moored to the pile revetment by drag lines. The brush of which the mattresses are composed is brought to these boats by small barges. A head is first constructed by binding together a number of hardwood poles with wire. It is made about 2 feet in diameter, and as long as the mattress is wide. A wire cable and a wire strand are then fastened at intervals of 8 feet to the head. Next, 12" fascines are placed parallel to and against the head end and fastened by a turn of the wire strand and a clamp under the cable. A second is then placed about 10 feet from the first. Mooring and shackle lines, in addition to the cables and wire strands are fastened to the two heads. Lines of poles are placed longitudinal about 8 feet apart, the full width of mattress to stiffen it and to serve as barriers to prevent stone ballast used from shifting while the mattress is being sunk. After completion, the mattresses were sunk by first loading them with rock brought on with wheelbarrows until their flotation was destroyed, and then by floating barges over them, and throwing rock on by hand. In many cases where

the rock was difficult to get, a concrete ballast was used. This ballast was composed of Portland cement and river sand and gravel, the ratio being 1 part cement to 15 parts sand or gravel. After the mattress is down, the upper bank is brought to a slope of about 1 to 3 by hydraulic graders, and paved with rock or concrete instead of the willow shore mat, which is destroyed by natural decay in about 3 years. The cost of this form of mattress was about $50.00 per lineal foot.

LUMBER MATTRESSES. In recent years a large number of lumber mattresses have been used. These mattresses were constructed of a cheap grade of lumber, and are formed by weaving strips from four to six inches wide, over and under planks laid longitudinally about 5-1/2 feet apart. They require less bulk of lumber and of stone than brush mattresses and can be built faster and cheaper. They break up rather badly when piles are driven through them, and are not so satisfactory as the fascine form.

SPURS. Submerged spurs are rather an improvement on the contraction dike. They are made in the form of long cribs and are placed perpendicular to the bank at intervals of about 500 feet. Their foundation is made by sinking a mattress. The cribs are built of willow poles and brush fastened by wires and spikes, and have pockets in them, in which rock is placed in order that they may be sunk. They were first used in New Orleans in 1884. Their purpose was to protect the bank immediately at the point they occupied, and indirectly protect the intermediate space by deposit due to eddy and dead water formed by their position relative to the swift current water.

The general dimensions of crib are governed by the profile of bank immediately at the point where the dike is located. Spurs have proven beneficial and permanent at intervals of 500 feet in bends of large radius with light currents and strong bank material, but in sharp bends composed of light soil, even when spaced short distances apart, they are only locally effective and are unsatisfactory.

The things which make the revetment work on the Mississippi difficult to construct and maintain, are: the excessive variation in the height of water surface and the volume of discharge, swift and changing currents, the great depth, caving bends, and the short season when the water is at a sufficiently low stage to admit of the building and sinking of mattresses. Notwithstanding all these difficulties, the revetment work undertaken on the Mississippi River is by far the largest in the world. Mattresses with a superficial area of 768 acres have been sunk to the bottom of river in depths 80 to 100 feet, in currents 5 to 8 feet per second. Spurs, 430 feet by 60 feet, containing 80,000 feet of lumber, 2,000 tons of rock and nearly 2,000 tons of iron, have been placed in 150 feet of water.

Judging from the reports of the -U. S. A. engineers, it would seem that while bank revetment furnishes a very good improvement, it is entirely too expensive to be used at this time.

RESERVOIRS.

The only place along the Mississipi that reservoirs have been tried is at the headwaters in Minnesota. The system above St. Paul is operated by impounding the waters in excess of the natural low-water flow at all times, when this excess is not needed by navigation, and releasing it during the low-water navigation. These reservoirs have been constructed by the Government principally for the benefit of commerce, and secondarily, for the prevention of floods. The following benefits are claimed to be derived from the reservoir system: (1). They prevent floods, or reduce their intensity. (2). They furnish a sure supply of water for navigation during the low-water season. (3). They furnish water for irrigation purposes. (4). They prevent the polution of water used for domestic purposes during the winter.

The work on reservoir construction was begun in 1881 at the head waters of the river above St. Paul. This place is very well adapted for such work. The surrounding country is flat and the soil of little value. The land in the region was largely the property of the U. S. Government, and, therefore, little trouble was experienced in making use of it. On account of the topography of the country, the reservoirs are shallow and of large area. The first reservoir dam was completed in 1884, at Winnibigashish Lake. The reservoir at this place has a capacity of five billion cubic feet. Since that time there have been four other dams completed, one at

Leech Lake, one at Pokema Falls, one in the Pine River, and one at Sandy Lake. The first two were completed in 1884, and have capacities of 30 and 4.7 billion cubic feet, respectively. The third dam was completed in 1886, and has a capacity of 7.5 billion cubic feet. The last one was completed in 1895 and holds about 2 billion cubic feet of water.

The first dams built were earthern embankments, with a water tight diaphram made of sheet piles driven along the axis of the middle line. Two other lines of piles were driven, one at the foot of the lower slope, and one at the foot of the upper slope. The water was discharged through the dam by means of sluice ways. These sluice ways were at the bottom of a simple wooden crib work, which supported them, and were opened and closed by means of vertically moving slide valves, operated by machinery.

About fourteen years after the Winnibigashish and the Leech Lake dams were completed the timber work in them became so rotten that the dams were unsafe. A general defiency act was approved July 7, 1898, which authorized the renewal of the two dams mentioned. Their reconstruction was completed in 1900, all the timber parts being replaced by concrete or masonry. The Government intends to replace the timber parts of the other dams also with concrete and masonry.

These dams have proven to be a great benefit to navigation below St. Paul. Before they were constructed, the stage of the river at St. Paul would fall as low as 3 inches, but since the dams have been in operation, it is possible to keep

the gauge from ever falling below 3 feet. The influence of the dam is felt as far down the river as Dubuque, where a raise of 3 inches has been observed by Signal Service officers. On the 424 miles of river above St. Paul, a still greater effect is obtained. Few steamboats, however, go above St. Paul on account of the obstructions produced by the logging industry.

Although the reservoirs constructed have been of benefit to navigation, there is a great deal of local opposition to the "Reservoir System", due to the fact that much land is necessarily overflowed around the edges of the reservoirs. Some engineers have proposed reservoirs for the basin in the Mississippi Valley, but the Army Engineers are opposed to them. It is believed by most people that other forms of improvements, such as levees, dikes and revetments, and dredges are far more practical and economical.

CANALS AND LOCKS.

The most important canals and locks built along the Mississippi are those at Keokuk, Iowa, and those at DesMoines, Iowa. These were built to furnish a means for boats to get around the rapids in the river at those places. The canal at Keokuk is 8 miles long and has three locks with a total lift of 18 feet. The Des Moines canal affords a draft of five feet at extreme low water, and each of its three locks have an available length of 325 feet, and a width of 78-1/2 feet.

CONCLUSION.

A great amount of work has been done on the Mississippi River at a very large expense. Some of the work has answered the purpose for which it was done, while some has proven a complete failure. The improvement that has proven the most beneficial is that by the levees and by bank revetments. When the river is completely reveted, it will cover every bend into which the current sets, 600 miles in all, between Cairo and New Orleans. When this is done it will not only provide a clear channel, but, in addition, will give a safe bank for the farmers back of the river, a safe foundation for levees, and will make land in the valley which is now worth \$20.00 per acre, worth \$150.00 or more. It would be cheaper and far more practical to improve the river for the purpose of reclaiming the low lands along the river than trying to improve it for the purpose of navigation.

It has been argued by many newspaper men and a few engineers that it is practical to make a deep waterway course through the United States by way of the Mississippi River but the more experienced engineers discredit this idea. They base their beliefs on the following facts: The lower boat transportation rates do not measure the cost of water transportation- To it must be added charges for wharfage, teaming, and insurance; boat transportation on smaller streams is characterized by exposure of merchandise to the elements while on the bank awaiting, or discharged from the boat: shipments transferred from or to rail routes must be handled in detail;

time schedules affecting passenger traffic, deranged often by low-water, and at times by high-water, are frequently uncertain; freight, on the contrary, is often delivered more quickly by water; capacity of boats may be insufficient to provide transportation as needed; recompense for damages to freight in transit is difficult to determine in amount or to collect.

Enumerating the above serves to accentuate the advantages of rail transportation, even at a higher first cost. In place of wharfage charges, and exposure of merchandise to the elements, is the railroad freight house, or it may be the car on siding, minimizing, or even abolishing teaming. In carloads freight is transferred from one line to another without handling of freight; less than carloads, without teaming. Increase in freight is met by increase in cars; time schedules are independent of water stages as a very general rule.

While the work of bank protection has been highly successful, as has also the jetties at the mouth of the river, the amount of good done does not seem to justify the expense. If all the appropiations were devoted to the protection of the low-lands, instead, of so much spent for the improvement of navigation, better results would be obtained at a great deal less cost.